Coronary Revascularization Trends in the United States, 2001-2008

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Context Coronary revascularization is among the most common hospital-based major interventional procedures performed in the United States. It is uncertain how new revascularization technologies, new clinical evidence from trials, and updated clinical guidelines have influenced the volume and distribution of coronary revascularizations over the past decade.

Objective To examine national time trends in the rates and types of coronary revascularizations.

Design, Setting, and Patients A serial cross-sectional study with time trends of patients undergoing coronary artery bypass graft (CABG) surgery or percutaneous coronary interventions (PCIs) between 2001 and 2008 at US hospitals in the Healthcare Cost and Utilization Project’s Nationwide Inpatient Sample, which reports inpatient coronary revascularizations. These data were supplemented by Medicare outpatient hospital claims.

Main Outcome Measures Annual procedure rates of coronary revascularizations, CABG surgery, and PCI.

Results A 15% decrease ($P < .001$) in the annual rate of coronary revascularizations was observed from 2001-2002 to 2007-2008. The annual CABG surgery rate decreased steadily from 12743 (95% confidence interval [CI], 1663-1825) CABG surgeries per million adults per year in 2001-2002 to 1081 (95% CI, 1032-1133) CABG surgeries per million adults per year in 2007-2008 ($P < .001$), but PCI rates did not significantly change (3827 [95% CI, 3578-4092] PCI per million adults per year in 2001-2002 vs 3667 [95% CI, 3429-3922] PCI per million adults per year in 2007-2008, $P = .74$). Between 2001 and 2008, the number of hospitals in the Nationwide Inpatient Sample providing CABG surgery increased by 12% (212 in 2001 vs 241 in 2008, $P = .03$), and the number of PCI hospitals increased by 26% (246 in 2001 vs 331 in 2008, $P < .001$). The median CABG surgery caseload per hospital decreased by 28% (median [interquartile range], 253 [161-458] in 2001 vs 183 [98-292] in 2008; $P < .001$) and the number of CABG surgery hospitals providing fewer than 100 CABG surgeries per year increased from 23 (11%) in 2001 to 62 (26%) in 2008 ($P < .001$).

Conclusions In US hospitals between 2001 and 2008, a substantial decrease in CABG surgery utilization rates was observed, but PCI utilization rates remained unchanged.

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States. Substantial changes in the overall volume of revascularizations or the relative use of CABG surgery vs PCI would have important ramifications on clinical outcomes, health care costs, and the future organization and delivery of hospital-based cardiovascular care. Therefore, the goal of our study was to use a representative national sample of hospitalization claims to estimate temporal trends in the annual volume of coronary revascularization procedures between 2001 and 2008.

METHODS
Study Data
The University of Pennsylvania’s institutional review board approved the study protocol. Data were obtained from the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project—Nationwide Inpatient Sample (NIS) files between 2001 and 2008. The NIS data sets contain patient-level hospital discharge data provided by states (n=42 in 2008) that participate in the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project. The NIS includes data from approximately 1000 hospitals and is designed as a stratified, 20% representative sample of all nonfederal US hospitals. Criteria used for stratified sampling of hospitals into the NIS include hospital ownership, patient volume, teaching status, urban or rural location, and geographic region. Weighting the patient-level observations in the NIS data sets to account for the complex sampling scheme provides estimates for the entire US population of hospitalized patients. Each record in the NIS includes all procedure and diagnosis codes recorded on each patient’s hospital discharge abstract. Because the NIS is derived from state-mandated hospital discharge reports, it includes all claims from each selected hospital regardless of payer or insurance status.

Identifying Coronary Revascularizations
Coronary revascularizations were identified on NIS claims by the appearance of procedure codes 36.01 to 36.07, 36.09, or 00.66 for PCI, or by codes 36.1x for CABG surgery. A claim was classified as a DES if procedure code 36.07 appeared or if the claim was assigned to diagnosis related group (DRG) 526-527 between April 1, 2003, and September 30, 2005; DRG 557-558 between October 1, 2005, and September 30, 2007; or DRG 246-247 after October 1, 2007. The claim was designated as a bare metal stent (BMS) if there was no DES coding and if procedure code 36.06 or codes 00.45 to 00.48 combined with 00.66 appeared, or if the DRG assignment was 116 between January 1, 2001, and September 30, 2001; 517 between October 1, 2001, and September 30, 2005; 555-556 between October 1, 2005, and September 30, 2007; or 248-249 after October 1, 2007. The claim was assigned as a nonstenst coronary angioplasty if codes 00.66, 36.01 to 36.05, or 36.09 appeared and were unaccompanied by any code indicating a DES or BMS.

Calculation of Procedure Rates
The NIS was constructed as a 20% stratified random sample of US hospitals. Accordingly, the population at risk for treatment at these hospitals was a 20% random sample of the US population. Because our study excluded pediatric procedures, we calculated procedure rates as the number of CABG surgery, DES, BMS, and nonstent coronary angioplasties reported in the NIS sample, weighted according to the NIS stratified sampling scheme, divided by 20% of the total number of US adults during the same periods. Estimates of the size of the US adult population in each year between 2001 and 2008 were obtained from the US Census Bureau.

Measuring Outpatient PCI
The NIS is assembled solely from hospital inpatient discharge data. Although CABG surgery is invariably an inpatient procedure, our prior work has determined that between 6% and 18% of PCI procedures were performed on outpatients, including low-risk elective procedures performed at hospitals in so-called 23-hour stays. These outpatient PCI procedures would not be included in the NIS. For Medicare beneficiaries, however, outpatient procedure claims are available from the Centers for Medicare & Medicaid Services. We used these outpatient Medicare procedure claims to identify PCI by the appearance of Healthcare Common Procedure Coding System codes 92980, 92981, 92982, or 92984. Codes 92980 and 92981 on outpatient claims specifically indicated stent use, and the concurrent appearance of codes C1874, C1875, G0290, or G0291 further indicated use of a DES.

We estimated the ratio of outpatient to inpatient PCI claims, using a 100% national sample of Medicare claims, for beneficiaries aged 65 to 69 years in each calendar quarter between 2001 and 2008 as a proxy measure for the national mean outpatient:inpatient PCI ratio. Because prior reports of the demographics of PCI recipients indicate their mean age is in the mid-60s, the outpatient:inpatient PCI ratio of patients aged 65 to 69 years would reasonably approximate the ratio for all patients with PCI. Because the likelihood of obtaining outpatient PCI may be correlated with the type of PCI received, we separately calculated outpatient:inpatient ratios for recipients of DES, BMS, and nonstent angioplasty. These outpatient:inpatient ratios derived from Medicare data were then multiplied by the quarterly inpatient PCI rates generated from NIS data to estimate the national outpatient PCI rate for each calendar quarter. In addition, the outpatient PCI rate was added to the inpatient PCI rate generated directly from the NIS to obtain the total PCI rate.

Validation of NIS Count Data
Because NIS hospitals were not designed specifically to represent the national provision of cardiovascular hospital services, it is possible that national rate estimates using the NIS may not perfectly approximate the rates in the full population of US coronary revascularization hospitals. To assess the level of agreement between the NIS and

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national claims data, we compared CABG surgery and PCI quarterly national count estimates from NIS for Medicare beneficiaries older than 65 years to the counts of CABG surgery and PCI claims obtained from a 100% sample of Medicare inpatient claims for 2001 to 2008. 

**Differences in Revascularization Between 2001 and 2008**

To assess for differences between patients with revascularization in 2001 compared with 2008, we compared age, sex, and geographic distributions between CABG surgery recipients in 2001 vs 2008, as well as PCI recipients in 2001 vs 2008. Because race is unreported for many hospitals in NIS data, we separately calculated the 2001-2008 difference in race percentages among CABG surgery and PCI recipients using Medicare claims for CABG surgery or PCI between 2001 and 2008. After excluding hospitals reporting fewer than 5 coronary revascularizations per year, we then examined changes over time in the number and case-volume of the hospitals performing CABG surgery or PCI between 2001 and 2008.

**Statistical Analyses**

Trends in the annual rates of CABG surgery and PCI were assessed using negative binomial regressions with procedure count as the dependent variable and calendar quarter as the key independent variable, with the size of the population at risk as an offset term. Characteristics of patients undergoing CABG surgery or PCI in 2001 vs 2008 were compared with χ² tests, except age, which was compared with a t test. Characteristics of hospitals providing CABG surgery or PCI were compared using χ² tests for categorical variables and the Wilcoxon rank sum test for differences in hospital caseloads. All statistical analyses were performed using SAS version 9.2 (SAS Institute Inc, Cary, North Carolina) or STATA version 11.1 (Stata Corp, College Station, Texas). All statistical tests were 2-sided, with P < .05 indicating statistical significance.

**RESULTS**

For each year between 2001 and 2008, the NIS data set included all-payer inpatient discharge data from 212 hospitals per year in 2001 to 241 hospitals per year in 2008 that provided CABG surgery and from 246 hospitals per year in 2001 to 331 hospitals per year in 2008 that provided PCI. Medicare PCI claims from patients aged 65 to 69 years indicated outpatient PCI became more prevalent over time, increasing from 5769 of 77 080 PCI (7.5%) in 2001 to 16 269 of 96 580 PCI (16.8%) in 2008. The annual US rate of coronary revascularizations decreased by 15% from 5569 (95% confidence interval [CI], 5315-5835) procedures per million adults per year in 2001-2002 to 4748 (95% CI, 4532-4975) procedures per million adults per year in 2007-2008 (P < .001) (TABLE 1). There was a 38% decrease in the annual CABG surgery rate between 2001 and 2008, with the CABG surgery rate decreasing steadily throughout the 8-year period (FIGURE 1) from 1742 (95% CI, 1663-1825) per million adults per year in 2001-2002 to 1081 (95% CI, 1032-1133) per million adults per year in 2007-2008 (P < .001). However, the PCI rate changed minimally with a 4% decrease from 3827 (95% CI, 3578-4092) per million adults per year in 2001-2002 to 3667 (95% CI, 3429-3922) per million adults per year in 2007-2008 (P = .74). Projected to the entire US population, these rate changes implied that 130 000 fewer CABG surgeries were performed in 2008 compared with 2001, and the 2001-2008 decrease in the total number of US coronary revascularizations was 80 000 (7%) from a 2001 total volume of 1.21 million revascularizations.

**Patient and Hospital Characteristics**

Statistically significant decreases in CABG surgery rates between 2001 and 2008 were observed across sex, age, racial, and regional subgroups (FIGURE 2). Comparison of the demographics of CABG surgery recipients and PCI recipients between 2001 and 2008 revealed slight differences in age, sex, racial, and geographic distributions over

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Twelve percent more hospitals provided CABG surgery in 2008 than in 2001 (241 vs 212 hospitals in NIS providing procedure, \(P = .03\)), and a 26% increase in the number of PCI hospitals occurred between 2001 and 2008 (246 vs 331 hospitals in NIS providing procedure, \(P < .001\)). The increase in the number of hospitals providing CABG surgery combined with the decrease in national CABG surgery rates resulted in a 28% decrease in the median caseload per hospital (median [interquartile range], 253 [161-458] in 2001 vs 183 [98-292] in 2008; \(P < .001\)) and a substantial increase in the number of hospitals that provided fewer than 100 CABG surgeries per year (23 [11%] in 2001 to 62 [26%] in 2008, \(P < .001\)).

**DES Percentage of PCI Between 2001 and 2008**

Drug-eluting stents were approved by the US Food and Drug Administration in April 2003. By the third quarter of 2005, the use of DES as a percentage of all PCI procedures peaked at nearly 90% (FIGURE 3). Percentage use of DES subsequently decreased during 2006-2007 to 26 353 of 43 330 PCI procedures (61%) in the first quarter of 2008, followed by a sustained increase in DES use through the end of 2008. Data from the final calendar quarter in 2008 indicated DES was used in 29 002 of 42 407 PCI procedures (68%).

**Validation of NIS Estimates With Medicare Claims Data**

Comparisons of the counts of CABG surgery and PCI estimated by NIS among Medicare beneficiaries older than 65 years compared very closely to the actual counts of CABG surgery and PCI claims submitted to Medicare between 2001 and 2008 (eAppendix; available at http://www.jama.com). Quarterly CABG surgery counts differed by a mean value of 0.1% (range, –14% to 13%) and quarterly PCI counts differed by a mean of 0.2% (range, –9% to 9%) between these 2 data sources. Medicare claims revealed similar trends in CABG surgery and PCI rates be-
between 2001 and 2008 as were observed in the NIS. Further analysis of Medicare PCI claims, which unlike NIS data include patient identifiers, also revealed that the percentage of all PCI procedures that were repeat PCIs (ie, PCI performed within 365 days of a prior PCI) decreased slightly from 16.1% in 2001 to 12.9% in 2008 (P for trend = .003).

**COMMENT**

Although there was only a modest decrease in the annual rate of coronary revascularizations in the United States between 2001 and 2008, we found a substantial decrease in the rate of CABG surgery, with approximately one-third fewer CABG surgeries being performed in 2008 compared with 2001.
This decrease in CABG surgery rate occurred as a roughly linear trend throughout the 8-year period, suggesting that the decrease was not triggered by any single event occurring during the past decade, such as the introduction of competing technologies, advances in CABG surgical techniques, publication of clinical trials, or issuance of clinical guidelines. During the same 8-year period, there was an increase in the number of US hospitals providing CABG surgery, therefore causing a substantial decrease in the median hospital CABG surgery case volume and a marked increase in the number of US hospitals with relatively low (ie, <100 cases per year) annual CABG surgery case volume.

Decrease in CABG Surgery Rates

Clinical Implications. Although it is possible that the decrease in CABG surgery rate was entirely unrelated to PCI utilization and it cannot be known with certainty whether physicians were increasingly substituting PCI for CABG surgery during the past decade for the treatment of coronary artery disease, our findings suggest the possibility that several thousand patients who underwent PCI in 2008 would have undergone CABG surgery had patterns of care not changed markedly between 2001 and 2008. Our data imply a sizeable shift in cardiovascular clinical practice patterns away from surgical treatment toward percutaneous, catheter-based interventions. However, the results of the recent SYNTAX trial indicated CABG surgery remains the better choice for coronary revascularization among patients with previously untreated 3-vessel or left main coronary artery disease, even in the DES era. The clinical indications for CABG surgery validated by the SYNTAX trial are virtually identical to the class IA indications for CABG surgery published by the American College of Cardiology/American Heart Association in 1999, indicating stability in the published evidence supporting CABG surgery use. The decreasing CABG surgery rate during this period of stable evidence and guidelines implies either overuse of CABG surgery in 2001, which has been progressively corrected by better patient selection, or increasing underuse of CABG surgery between 2001 and 2008 because patients who would have been optimally treated with CABG surgery were instead treated with PCI.

Other published data suggest CABG surgery use decreased over time for treatment of coronary artery disease. Gogo et al examined 2002-2005 data from 365 US hospitals participating in an American College of Cardiology/American Heart Association Guidelines Quality Improvement Initiative and found that CABG surgery was used in only 40% of patients with 3-vessel disease in late 2005 compared with nearly 50% in early 2002. Similarly, Frutkin et al examined PCI indications from the National Cardiovascular Data Registry and determined that after the introduction of DES in 2003, increasing numbers of patients with class I clinical indications for CABG surgery underwent PCI. Our results extend these findings by demonstrating that the trend in decreasing CABG surgery rates was occurring in a broadly representative sample cohort of US hospitals providing CABG surgery, persistent across 8 years, and resulted in a marked reduction in the rate of CABG surgery procedures performed at the end of the decade compared with the beginning.

Potential Explanations. Because our data could not distinguish which patients with revascularization were more appropriate candidates for CABG surgery vs PCI, and because our data could not identify patients in later years who would have undergone CABG surgery in prior years, it was not possible to measure the characteristics of the patients whose care was “shifted” toward PCI between 2001 and 2008. It is possible that this group included many patients with less compelling clinical indications for CABG surgery over PCI, such as 2-vessel or non–left-main single-vessel coronary artery disease. It is also possible that the shift involved patients who were at very high risk for adverse perioperative outcomes from cardiac surgery, although it is unlikely that large numbers of such patients would have undergone CABG surgery in 2001, because alternative treatments were available. Increasing use of primary PCI for the emergent treatment of acute myocardial infarction between 2001 and 2008 may have obviated the need for additional coronary revascularization and thus decreased the CABG surgery rate. However, our observations combined with those of prior investigators suggest that a sizeable fraction of patients who did not undergo CABG surgery in 2007-2008 might have been appropriate CABG surgery recipients.

Hospital Volume of CABG Surgery

The decrease in the national case volume of CABG surgery was accompanied by an increase in the number of US hospitals providing CABG surgery. The combination of these phenomena implies that over time greater numbers of patients were obtaining CABG surgery at hospitals with low volumes of CABG surgery. Although there is controversy in the literature on whether low-volume hospitals inherently have worse CABG surgery outcomes, our findings highlight the increasing role of low-volume hospitals in the provision of CABG surgery.

Variation in DES Use

Changes in PCI market share between DES and BMS have been previously reported among selected subsets of US hospitals, and these changes possibly reflect a high level of clinician enthusiasm for DES in the years immediately following US Food and Drug Administration approval, followed by a “cooling off” period after publication of data suggesting DES safety concerns (ie, late in-stent thrombosis), as well as increasing clinician awareness of the imperative for DES patients’ adherence to long-duration antiplatelet therapy following DES implantation. Our results extend these
prior findings to a national sample of hospitals and provide further evidence that PCI practice patterns involving the choice of DES or BMS were highly volatile in the years following DES approval. An important implication of this volatility is that thousands of patients may have received DES during the peak years (2004-2005) who would have instead received BMS in 2007-2008. Whether these patients were appropriately treated with DES instead of BMS during these years of high enthusiasm for DES is uncertain.

Stable PCI rates between 2001 and 2008 were unanticipated, because clinical trials consistently have reported that DES reduces a recipient’s likelihood of repeat target vessel revascularization due to lower rates of subsequent restenosis. Our analysis of Medicare claims indicated the rate of repeat revascularization did in fact decrease during the DES era; therefore, an overall decrease in PCI rates subsequent to the introduction of DES would have been unsurprising. However, the stability of the PCI rate, combined with our findings from Medicare claims of decreasing rates of repeat PCI, suggests that there are increasing numbers of patients receiving PCI over time. Recipients of PCI in 2008 possibly included patients who would have been treated with CABG surgery, not PCI, if the coronary revascularization practice patterns of 2001 had not subsequently changed.

Limitations

Our national estimates for CABG surgery and PCI rates were derived from a 20% sample of US hospitals, with the sample designed to approximate the national distribution of key hospital characteristics, including location, ownership, volume, and academic status. Although the NIS sampling design is statistically sound and the NIS has been used extensively in prior research to estimate national health care trends, it is possible that coronary revascularization or its subtypes were either overrepresented or underrepresented by the sample. However, the number of CABG procedures and PCI procedures among NIS patients who were Medicare beneficiaries closely approximated the volume of procedures indicated by 100% Medicare claims data. This agreement between independent data sources increases our confidence that the NIS accurately represented national rates of coronary revascularization procedures.

Our method of estimating percentages of outpatient PCI was possibly inaccurate, because this ratio was derived solely from a subset of Medicare beneficiaries aged 65 to 69 years rather than from all patients undergoing PCI. However, as the mean age of US patients undergoing PCI is approximately 64 years, the national ratio of outpatient:inpatient PCI among all patients approximates the ratio observed among patients aged 65 to 69 years. In addition, because outpatient PCI remains relatively infrequent, a systematic bias in our estimate of the outpatient PCI fraction would not have changed our findings substantially.

The NIS does not include detailed information about patient clinical characteristics, such as coronary anatomy, angina class, ejection fraction, medications, surgical risk, or smoking status, which could explain changes over time in utilization of CABG surgery or PCI. Furthermore, the absence of these variables complicates comparisons of revascularization practices across hospitals, and therefore a detailed exploration of the drivers of the time trends we observed is beyond the scope of our study. In addition, the NIS does not report coronary revascularizations occurring in federal hospitals, such as those operated by the US Department of Veterans Affairs, US Department of Defense, or the Indian Health Service. Although these hospitals represent only a small fraction of the national health care system and thus exclusion of their procedures is unlikely to affect our primary findings, it is likewise unknown whether the trends we observed are applicable to patients in federal health care systems.

In conclusion, although the total rate of US coronary revascularization decreased modestly between 2001 and 2008, there was a substantial decrease in the CABG surgery rate. Between 2001 and 2008, the rate of PCI did not significantly change; however, there were continual changes in the frequency of stent types used for PCI.


